Aging of perovskite solar cells

Perovskite solar cells (PSCs) have reached the highest performances exceeding those of established technologies that have been carefully optimized for decades. Their high-power harvests and low-production costs have attracted serious industry attention from established companies and have led to the founding of multiple start-up companies. However, for commercial products, long-term stability is crucial. Thus, for perovskites to succeed, an informed discussion on a detailed degradation study is required.

Figure 1 shows that three typical architectures of PSCs are mesoporous architecture, planar architecture and inverted architecture, which also can be divided into n-i-p (mesoporous architecture and planar architecture) and p-i-n (inverted planar architecture) architectures.

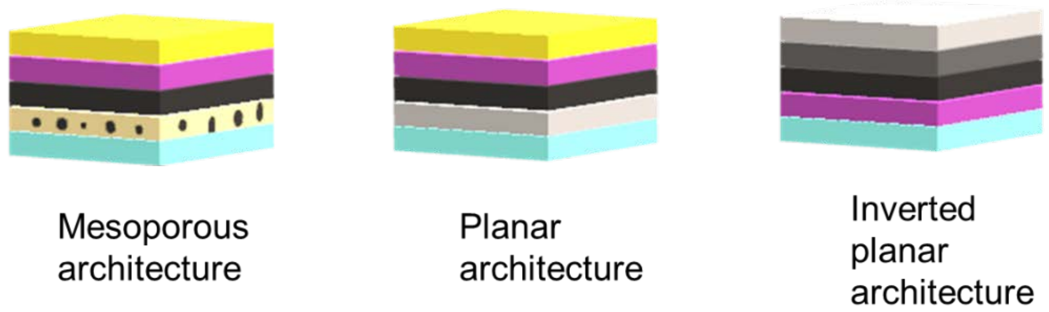

Figure 1. Three architectures of perovskite solar cells with the perovskite layer shown in purple.

Different architectures have different degradation behavior under operational conditions. In addition, one important observation in aging high-performance PSCs is the possible presence of "reversible losses," i.e., the efficiency improvement obtained by remeasuring after recovery in the dark. Interestingly, the aging behavior is symmetric to that of regular PSCs. Under MPP tracking, regular PSCs lose part of their initial efficiency, while inverted PSCs gain it. In the same way, after resting in the dark for several hours at open circuit, the regular device recovers partially, while inverted PSCs lose efficiency ("reversible bonus"). While the origin of this effect requires further extensive research, this example underlines the importance of establishing a new aging standard that systematically considers reversible energy losses/gains under relevant solar cell operating conditions, including effects of day and night cycling.

To ensure economic feasibility and competitive levelized cost of electricity, new photovoltaic (PV) technologies must offer long-term stability alongside high power conversion efficiency (PCE). For instance, the lifetime expectation for a PV module in a power plant is 20–25 years, to match the reliability of silicon-wafer-based modules. At present, the long-term stability of emerging technologies such as organic photovoltaic (OPV) cells, dye-sensitized solar cells (DSSCs) and halide perovskite solar cells (PSCs) is not meeting this target and improvements are hampered by a lack of understanding of the module failure modes. The existing qualification tests described in the International Electrotechnical Commission (IEC) standards on terrestrial PV modules (such as IEC 61215) are designed for the field performance of silicon panels to screen for well-understood degradation modes generally associated with issues at the module level. These tests, however, are unlikely to be well-suited to OPV cells, DSSCs and PSCs because of their fundamentally different material properties and device architectures. In fact, various reports have shown that the stability of these devices cannot be fully assessed by the procedures developed for conventional PV products, which led to the publication of various studies that attempted to understand the degradation mechanisms in emerging PV systems. Unfortunately, these studies lacked consistency in the assessment and reporting procedures which prevented data comparison and consequently the identification of various degradation factors and failure mechanisms. Regarding such shortcomings, consensus statement for stability assessment and reporting for perovskite photovoltaics based on the International Summit on Organic Photovoltaic Stability (ISOS) procedures have been suggested.

One aspect overlooked in earlier works is the effect of the atmosphere on device performance during operation. We investigated the degradation mechanisms of perovskite solar cells operated under vacuum and under a nitrogen atmosphere. [1] We find that light-induced phase segregation, lattice shrinkage and morphology deformation occur under vacuum. Under nitrogen, only lattice shrinkage appears during the operation of solar cells, resulting in better device stability. [1] Figure 2 shows synchrotron radiation based advanced scattering methods including grazing incidence small angle x-ray scattering (GISAXS) and grazing incidence wide angle x-ray scattering (GIWAXS). We focus on investigating degradation mechanisms of different architectures of perovskite solar cells under operational conditions based on the ISOS protocol with GISAXS/GIWAXS. Our aim is to explain both challenges, a deep understanding of fundamental physical processes under operational conditions, as well as a potential way to suppress the degradation behaviors, which allows for the development of accelerated aging routines to guide industrial development.

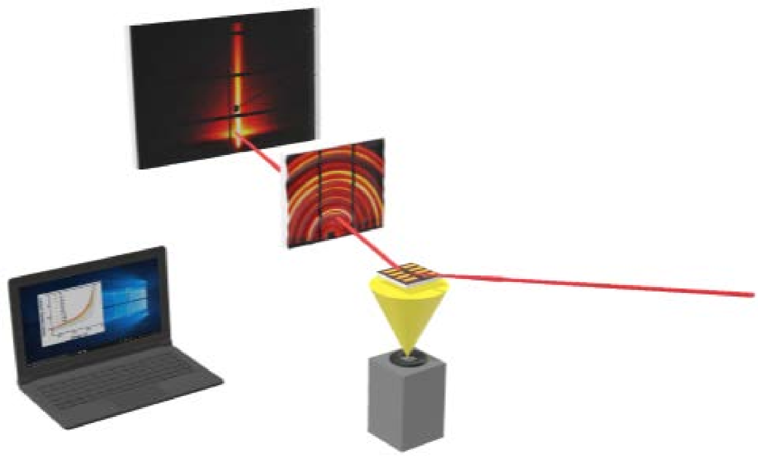

Figure 2. Sketch of synchrotron radiation based in-operando solar cells testing with GISAXS and GIWAXS

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1. R.Guo, D.Han, W.Chen, L.Dai, K.Ji, Q.Xiong, S.Li, L.K.Reb, M.A.Scheel, S.Pratap, N.Li, S.Yin, T.Xiao, S.Liang, A.L.Oechsle, C.L.Weindl, M.Schwartzkopf, H.Ebert, P.Gao, K.Wang, M.Yuan, N.C.Greenham, S.D.Stranks, S.V.Roth, R.H.Friend, P.Müller-Buschbaum
Degradation mechanisms of perovskite solar cells under vacuum and one atmosphere of nitrogen
Nature Energy **6**, 977-986 (2021)